CRREL REPORT 93-22

CRREL

2

Thermal Variation in Vegetated or Snow-Covered Background Scenes and Its Effect on Passive Infrared Systems

Lindamae Peck

November 1993

Abstract

The diurnal and seasonal variations in the magnitude of and rate of change of surface temperature have been investigated for vegetated and snow-covered ground under winter, summer and transitional weather conditions at a site in Vermont. The variability in thermal radiance is evident as changes in the proximity-to-alarm status of passive infrared detection systems. A mid-winter snow cover is the most favorable background because its associated thermal radiance changes are less dynamic than are the radiance changes of uniform grass covers in summer or mixed backgrounds of grass–thatch–soil following winter. Grass–thatch–soil backgrounds typically experience a larger diurnal range in temperature (from nighttime low to daytime high) and greater spatial variability in thermal radiance than do the uniform grass covers. The summer grass is more likely to be long enough to blow in the wind, thereby causing a change in thermal radiance as variously the sun-warmed, upper portion of the grass blades or the shaded (and therefore cooler) basal portion of the grass blades, and perhaps the sheltered soil, are momentarily exposed to the passive infrared system.

Cover: The three background scenes examined, having distinctly different impacts on thermal detection devices.

For conversion of SI metric units to U.S./British customary units of measurement consult *Standard Practice for Use of the International System of Units (SI)*, ASTM Standard E380-89a, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

CRREL Report 93-22

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Thermal Variation in Vegetated or Snow-Covered Background Scenes and Its Effect on Passive Infrared Systems

Lindamae Peck

November 1993

Prepared for
U.S. AIR FORCE ELECTRONIC SECURITY AND COMMUNICATIONS CENTER
and
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Dr. Lindamae Peck, Geophysicist, Geophysical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. This research was supported by the U.S. Air Force Electronic Security and Communications Center, under MIPR F4760-93-AVJ213, and the Office of the Chief of Engineers under DA Project 4A762784AT42, *Research in Snow, Ice and Frozen Ground*, Work Package, *Physical Security in Cold Regions*, Work Unit AT42-CH-PO1, *Cold Regions Effects on Intrusion Detection Systems (IDS)*.

Roger Berger, James Lacombe and Dr. Charles Ryerson, all of CRREL, provided technical review of this report and helpful discussions.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

CONTENTS

ILLUSTRATIONS

TABLES

Thermal Variation in Vegetated or Snow-Covered Background Scenes and Its Effect on Passive Infrared Systems

LINDAMAE PECK

INTRODUCTION

This report presents the results of a field experiment in which the diurnal and seasonal variations in thermal radiances from grass-covered and snow-covered terrain were determined using a passive infrared (PIR) system. The PIR response is determined by both the magnitude of and the differential rate of change in net thermal radiance within the field of view of each of two thermal infrared detectors. If both detectors experience the same radiance change simultaneously, then the PIR response does not change; however, if the detectors experience the radiance change sequentially, as would be the case if an object moved across the background thermal scene, then the PIR responds with a voltage change. A time-series record of PIR voltage output thus indicates the variation in space and time of the thermal radiances of the detectors' background scenes.

The PIR data were correlated with extensive site characterization data to identify the environmental factors controlling the observed changes in PIR response. On the basis of derived understanding of the daily and seasonal variability in thermal radiance, guidelines are presented for anticipating when a passive IR-based intrusion detection system is prone to environmentally caused nuisance alarms or false target detections.

FIELD EXPERIMENT

In October 1990 two PIR systems (ELTEC Instruments Model 862-71C IR-Eye Long-Range Passive Infrared Telescope) were installed at the CRREL intrusion detection systems (IDS) research site known as SOROIDS in South Royalton, Vermont, as part of a collaborative investigation of cold regions effects on the detection phenomenologies of exterior IDSs by CRREL and the Air Force Electronic Security and Communications Center. The ELTEC systems, hereafter referred to as PIRs, were placed facing each other in the grass-covered area between two parallel sections of chain-link fence (Fig. 1). They were separated by 50 m on a roughly east–west line of sight (leading to a designation of PIR-East and PIR-West based on location) and were inclined slightly (3.5°) below horizontal, caus-

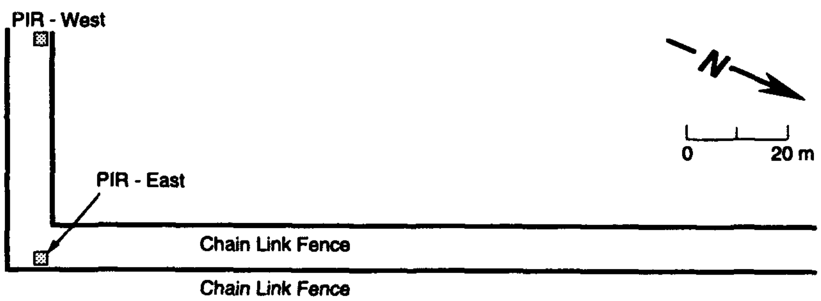


Figure 1. East and west PIRs at the SOROIDS site.

ing their fields of view to cover primarily the ground between them. The PIRs were operated continuously to provide a long-term record of environmentally caused changes in probability of detection and nuisance alarm rate, which are reported in Peck (1992).

A description of the optics and electronics of the ELTEC PIRs is given in Lacombe (1992) and Lacombe and Peck (1992), which present a model that predicts the PIR response to an object (intruder) characterized by its thermal contrast with the background, its rate of movement and its size. A single PIR has two infrared detectors (8- to 14-μm spectral band) with different but closely spaced fields of view. The output of these detectors is wired in a parallel-opposed manner so that a simultaneous, similar change in received thermal radiance at the two detectors produces no net response by the PIR, while a differential change in input to the two detectors causes a response determined by the magnitude and rate of change of the received thermal radiance. The net result of the PIR's detection and processing of a change in thermal radiance is expressed as a voltage that is a measure of the dynamics of the thermal scene.

The PIR automatically compares this test point voltage with a reference voltage that is determined by the sensitivity setting of the PIR. When the test point voltage equals or exceeds the reference voltage, an alarm is generated to indicate that an "intruder" is present. When no intruder is present, a change in the test point voltage indicates a differential change in the thermal radiance of the background scene. By monitoring the test point voltage, a times series record of the PIR's proximity-to-alarm status is obtained.

Beginning in November 1991, the response of the PIRs to a change in thermal radiance within their fields of view was directly determined through continuous monitoring of each one's test point voltage with a data logger. The voltages were sampled at 8-Hz frequency and the maximum, minimum and average values for the preceding 30 minutes were recorded every half hour. This data acquisition process produced 48 measurements representative of the dynamics of the thermal scene every day. Site characterization data (including air temperature, temperature of the loamy soil at the base of the grass layer, wind speed and direction, snow depth, precipitation, and incident and upward-directed radiation in the 0.3- to 3- and 3- to 50-μm bands) were also recorded at the same 30-minute increments as average, maximum and minimum or instantaneous values, depending on the parameter. Both PIRs were operated through 28 July 1992; since then, only PIR-West has been monitoring the dynamics of the thermal background scene at SOROIDS because the east device was damaged, perhaps by lightning.

The relevant spatial scale is the variation of surface temperature relative to the size of the field of view of a PIR's thermal detectors. For the PIR configuration at SOROIDS, the length of a thermal detector's field of view is slightly more than 50 m but its width is only about 0.25 m at its furthest extent, and it decreases toward the PIR. The detectors' fields of view are closely adjacent without overlapping. Each thermal detector's response is proportional to the net radiance from the long, narrow portion of the background that is within its field of view.

The relevant time scale is determined by the frequency response of the PIR's thermal detectors. The PIR electronics are intentionally designed to be sensitive to rapid changes in radiance, such as a walking person would cause, and to ignore gradual changes. The peak response of the thermal detectors is at 1 Hz. A combination of low spatial variability in the surface temperature of the ground cover and low rate of change of the temperature distribution would be the ideal, thermally stable background for an IR system having the optics and electronics of the ELTEC PIRs.

BACKGROUND SCENES

The record of PIR proximity-to-alarm status spans all the conditions typically encountered at a northern New England site in the course of a year. The usual seasonal sequence of ground covers (snow, thatch intermixed with new-growth grass and exposed soil, lush grass cover, dormant grass) and site weather produces distinctly different thermal background scenes. Two complementary studies involving unvegetated backgrounds (sand, gravel, asphalt and concrete) (Lacombe 1993) and developing a methodology for extrapolating northern New England results to other climatic regimes are in progress.

Snow-covered ground

The variability in thermal radiance from snow-covered ground depends on the physical characteristics of the snow, the underlying terrain and the weather. The spatial variability of the thermal signature of a snow cover primarily depends on its depth, which influences whether localized ther-

mal contributions from objects such as scattered rocks at the ground surface are apparent at the snow surface. Other factors causing spatial variability of the snow surface thermal radiance are inhomogeneities within the snowpack, lateral variations in emittance at the snowpack surface, the proximity of objects shadowing the snow surface and whether heat flow through the snowpack has been disturbed by compaction, such as footprints or tire tracks. Horizontal temperature variations on the order of 5°C over a few meters within a snow cover have been measured (Desrochers and Granberg 1986, Sturm 1991). One cause is plume-like convective heat flow through the snow cover, which may arise from a nonuniform temperature distribution at the ground/snow interface because of unevenly distributed moisture at the ground surface (Sturm 1991).

A snow cover is unique from other backgrounds in that there is a natural limitation on its temperature, which cannot exceed 0°C. The thermal radiance of the snow essentially depends on the magnitude of the available solar energy only while there is no melting; increases in solar input after the onset of melting do not produce increases in snow temperature (but when insolation is insufficient to maintain melting, the snow surface will cool). A corollary is that the maximum snow temperature need not necessarily occur during daylight hours, as for example, when a warm air mass moves into the area at night. These last two factors are responsible for temporal variations in thermal radiance from a snow cover that may show diurnal changes significantly different from those characteristic of other ground covers.

Summer grass cover

The PIRs at SOROIDS are located in an area that is planted with mixed grass. The strip of ground (50 × 9 m) is bounded by chain-link fences on three sides. There are no other substantial obstructions to wind flow over the area, and the only fixed objects to cast shadows are the fences and the pole mounts for the PIRs. Consequently, there is no preferential growth of grass in the area and by June there typically is a lush, uniform grass cover. Other than immediately following its weekly mowing (to a height of 4 in. [10 cm]), the grass is usually tall enough to blow in the wind.

Transitional ground covers

Following the final snow melt of the winter, the ground cover is patches of matted, old-growth grass or thatch, exposed soil where the grass was churned into mud during thaw periods, and new growth grass. Until the grass reestablishes itself, the ground cover is quite obviously a thermally inhomogeneous background. There is no regularity to the spatial distribution of the thatch, exposed soil and grass, all of which respond differently to heating and cooling in accordance with changes in insolation. The range in solar albedos represented by this background may be approximated from Table 1. The absorbed solar energy first dries the grass, thatch and soil. Strong surface heating of the thatch and soil then follows, but the grass preferentially consumes the solar energy in evapotranspiration rather than in sensible heat generation.

The last mowing of the growing season leaves the grass at a consistent height. During the transitional period before winter, the dormant grass is a spatially homogeneous background that becomes a uniform sublayer to the eventual snow cover.

DIURNAL VARIATIONS IN TEMPERATURE OF THE BACKGROUND SCENE

Four environmental parameters, recorded each half hour, independently show whether the surface of the current background (snow, grass, thatch–

Table 1. Surface albedos for solar radiation (after Lunardini 1981).

Surface	*Munn (1966)*	*Porkhaev (1959)*	*Van Wijk (1966)*	*Budyko (1974)*
Fresh snow	0.7–0.95	0.85	0.80–0.85	0.8–0.95
Old snow	0.7			
Melting snow			0.30–0.65	
Wet grass in sun	0.33–0.37	0.28		
Wet grass, no sun	0.14–0.26			
Dry grass	0.15–0.25	0.19	0.16–0.19	
Green grass			0.16–0.27	
Light colored bare soil		0.35		
Dark colored bare soil		0.15		

soil–grass or mixed) is warming or cooling. Of these, two are equally applicable to the entire fields of view of both thermal detectors. One is the incident solar radiation in the 0.3- to 3-μm bandwidth. This is measured with a pyranometer and includes both the direct component of sunlight and the diffuse component of skylight. The relative warming and cooling of the ground cover depends on the variation in magnitude of the insolation. The actual temperature distribution is determined by the heterogeneity of the ground cover and the range in thermal diffusivities of the ground cover components.

A second site-wide parameter is the air temperature, generally measured at a height of 2 m. During the winter, whether or not the surface of a snow cover is stabilized at 0°C because of melting may be deduced from the air temperature. Both heat conduction from warm overlying air and the release of latent heat from meltwater that refreezes within the snowpack can raise the surface temperature of the snow (Motoyama 1990). For other ground covers, local warming of the air occurs after any condensation (dew, frost) on the surface has melted and evaporated, and the ground cover has begun to warm under solar loading. Sensible heat flux to the air begins once the surface of the ground cover has become warm relative to the overlying air. The availability of sensible heat to warm the air over a vegetated surface increases in the afternoon if the vegetation, experiencing moisture stress, limits evapotranspiration to retard moisture loss, thereby reducing the amount of energy consumed as latent heat (Brunet et al. 1991, Rosenberg 1974). The surface temperature of the vegetation increases as evapotranspiration decreases (Soer 1980).

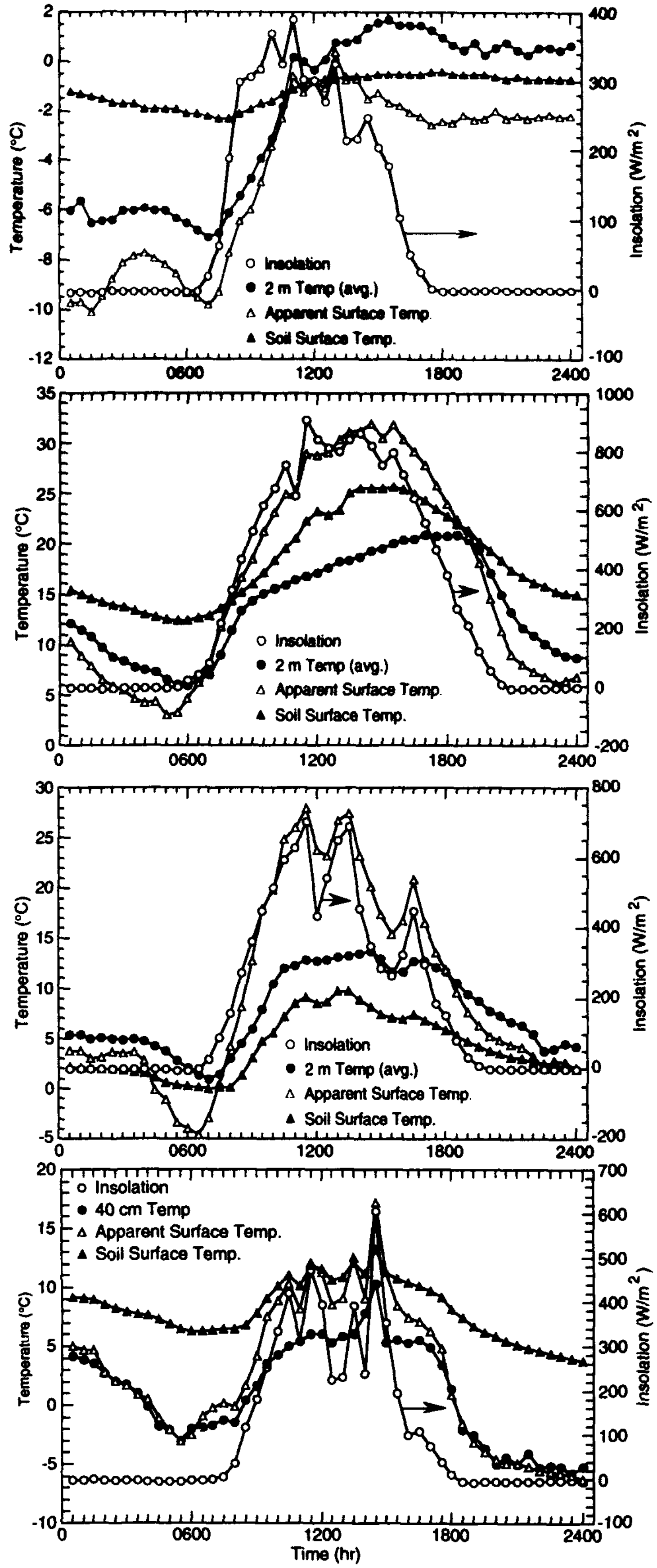
A third parameter is the near-surface temperature of the sandy loam soil. At SOROIDS this is measured with a copper-constantan thermocouple that is located slightly below the soil surface in a grass-covered area. This is a spot measurement that is valid only for other site locations having a similar surface condition. On sunny days during the spring and summer, this thermocouple would underestimate the surface temperature of grass, thatch or exposed soil because the grass layer overlying the soil where the thermocouple is embedded would insulate it from rapid temperature increases. On autumn days with lower air temperatures, the near-surface soil temperature is likely to be higher than that of the overlying grass cover because of residual ground heat from solar warming during the preceding summer.

The fourth parameter is the apparent surface temperature calculated from the upwelling long-wave radiation (3–50 μm) as measured with a downward-looking pyrgeometer. The field of view of the pyrgeometer is nominally a 180° hemisphere, but radiance received from an approximately 90° arc about the hemisphere's axis dominates. For a 1.5-m instrument height, this corresponds to a 1.2-m-diameter circular area on the ground surface. The equation used to convert radiation (W/m^2) to temperature (°C) is a linear regression fit to Planck's equation with the assumptions of black body emission by the ground cover and flat, 100% response over the 3- to 50-μm spectrum.* The actual surface temperature could be slightly different, depending on the emissivity of each portion of the surface. An apparent surface temperature derived from the upwelling long-wave radiation is applicable only to nearby areas where the spatial extent of the different components is similar to the sampling area of the pyrgeometer. The net radiance from mixed surfaces, such as clumps of grass surrounded by bare soil or scattered remnant patches of snow and ice on a vegetated surface, would not be adequately represented if the pyrgeometer viewed exclusively the soil, the grass or the snow. The error in calculated surface temperatures is estimated not to exceed 3°C for winter conditions and 4°C for summer conditions, based upon the pyrgeometer response and the derivation of the equation used.

Examples of seasonal differences in these four parameters are given in Figure 2.

On 24 February 1992 (Fig. 2a) insolation (maximum half-hourly average of 390 W/m^2) was typical for a SOROIDS winter day without snowfall or rainfall. Increases in the three temperatures lagged the onset of insolation by 1.5–2 hours and proceeded at significantly lower rates. On this sunny, calm (half-hourly wind gusts less than 3.5 m/s) day, the air temperature rose to above 0°C and the snow surface approached melting. The temperature of the soil beneath the shallow (2–4 cm) snow cover and dormant grass also showed the warming effects of the weather conditions, but much less dynamically. The variation in air temperature provides the closest match to relative changes (warming, cooling, stable) in the apparent snow surface temperature. The air and snow surface remained warm through the evening on this day because of regional weather patterns.

* Personal communication with J. Lacombe, Mechanical Engineer, CRREL, 1993.



a. Snow surface on 24 February 1992.

b. Grass surface on 23 June 1992.

c. Grass–thatch–soil surface on 10 April 1992.

d. Grass surface on 20 October 1991.

Figure 2. Time series records of air (30-minute average), ground surface (calculated) and soil surface (instantaneous) temperatures and incident solar radiation (30-minute average).

A typical sunny summer day at SOROIDS was 23 June 1992 (Fig. 2b). Peak insolation (907-W/m^2 maximum half-hourly average) was double the value on 24 February 1992 and the period of insolation was longer (0530–2100 hours vs. 0700–1800 hours on 24 February). The apparent surface temperature of the grass cover was calculated from the upwelling thermal radiance. The soil temperature is not an acceptable indicator of the surface temperature dynamics because its thermal inertia depresses its temperature variation in the course of the day, causing distinctly different temperature magnitudes and rates of change. The gradual rise in air temperature during the morning is a consequence of windy conditions (gusts of 6–13 m/s between 0800 and 1200 hours), which cause turbulent mixing of the air. In contrast, on calm, sunny summer mornings, the rate of increase in air temperature equals or exceeds that of the soil temperature, as was happening before the high winds on the morning of 23 June.

Transitional site conditions are represented by 10 April 1992 and 20 October 1991 (Fig. 2c and d). Both were days of erratic insolation because of passing clouds. The strong fluctuations in insolation are evident in the soil and surface temperatures on both days; the variation in air temperature is not representative of the relative changes in apparent surface temperature. The ground surface on 10 April was new growth grass poking through thatch and soil, while on 20 October it was uniform, mowed grass. Both surfaces were below 0°C for awhile before dawn. The 20 October soil surface and grass surface temperatures are determined for identical conditions, with the soil-surface thermocouple covered by a complete grass cover, and the pyrgeometer measuring radiance from a similarly grass-covered area.

The grass–thatch–soil surface of 10 April was warmer than the underlying soil surface throughout the daylight hours. The soil between 22.5 and 60 cm below the surface was still below freezing and showed no diurnal variation in temperature; heat flow was into the ground. On 20 October, following a summer of solar heating of the soil and under the influence of reduced solar warming and colder air in the autumn, it was warmest, 12°C, at a depth of 60 cm, the deepest measurement, and progressively cooler toward the surface. Heat flow was reversed and the soil surface, at the base of the grass cover, most often was warmer than the grass surface.

Of the three vegetated surfaces examined, that in the transitional period after winter had the greatest diurnal range in temperature (e.g., 10 April), when solar warming during daylight and strong radiational cooling at night together can cause a variation in apparent surface temperature on the order of 35°C. The intermediate range in surface temperature corresponds to summer conditions (e.g., 23 June), when higher and protracted insolation can cause the grass surface to be warmer during daylight than is the soil–thatch–grass surface of April, but the nighttime temperatures are also higher and so the diurnal range in surface temperature is less or comparable to that in April. The period before winter has the smallest diurnal range in surface temperature (e.g., 20 October), when solar warming of the surface is less and ambient air temperatures are significantly lower than in June or April.

Two implicit factors in this comparison of seasonal differences in the diurnal variation in apparent surface temperature at SOROIDS are geographic location and site topography. Seasonal changes in insolation are determined by geographic location. The portion of potentially available insolation, which is predictable on the basis of geographic location, that actually affects the surface temperature of a site's ground cover is determined by the presence of site-specific features, such as hills or large buildings, that may block the sun for part of the day. For example, SOROIDS is located in a river valley with nearby hills to the east and west. Solar warming of the site in the morning is delayed until after the sun clears the eastern hills; the western hills block late afternoon insolation, thus limiting its contribution to offsetting radiational cooling of the ground cover. The severity of these site-specific effects varies with the time of year. The specific magnitudes and rates of change of surface temperature presented here for SOROIDS are directly applicable to a site that has similar seasonal weather differences, similar ground covers and similar exposure to insolation. The pattern of diurnal and seasonal variations in thermal background scenes, of which SOROIDS provided examples, is broadly applicable.

DIFFERENCES IN RATES OF CHANGE OF SOROIDS SURFACE TEMPERATURES

Apparent surface temperatures on 28 days between September 1991 and March 1993 were calculated from the half-hourly averages of upwelling longwave (3–50 μm) radiation data. The site conditions on those days are given in Table 2. The rate of change of surface temperature from one period to

Table 2. Site conditions.

Date	Ground cover	Wind gusts (m/s)	Air temperature (°C)	Insolation Maximum (W/m²)	Insolation Sum (W/m²)
1991					
30 Sep	grass	———	–6.3 to 14.5	632	7,721
20 Oct	grass	———	–5.7 to 10.3	606	5,096
21 Oct	grass	———	–6.9 to 12.1	478	4,431
22 Oct	grass	———	0.9 to 18.9	501	6,025
1992					
23 Feb	snow	0.2 to 7.2	–5.5 to 3.2	599	4,410
24 Feb	snow	0.2 to 3.2	–7.1 to 1.5	390	4,727
25 Feb	snow	1.8 to 9.8	–1.2 to 0.6	99	713
26 Feb	snow	0.2 to 7.8	–1.2 to 3.8	292	2,415
9 Apr	gr–th–so*	0.4 to 10.8	–3.6 to 13.3	800	9,959
10 Apr	gr–th–so	0.8 to 10.8	1.0 to 13.7	702	9,006
12 Apr	snow	1.2 to 13.9	0.1 to 7.7	520	5,227
14 Apr	gr–th–so	0.6 to 13.0	–7.9 to 7.9	930	11,404
15 Apr	gr–th–so	0.5 to 11.3	–5.5 to 7.0	862	13,576
29 Apr	gr–th–so	0.2 to 11.9	–1.3 to 18.5	889	12,923
30 Apr	gr–th–so	0.5 to 8.6	0.2 to 18.0	815	7,742
1 May	gr–th–so	0.7 to 9.2	8.3 to 16.7	837	11,328
2 May	gr–th–so	0.6 to 13.0	7.9 to 16.0	424	4,584
3 June	grass	0.6 to 11.8	8.2 to 25.6	910	12,262
4 June	grass	0.3 to 6.1	9.6 to 27.7	886	12,661
5 June	grass	0.4 to 15.7	11.9 to 21.0	818	7,326
23 June	grass	0.6 to 12.7	6.0 to 20.9	907	15,211
21 Dec	grass	0.9 to 13.9	–7.2 to –1.9	339	3,228
22 Dec	grass	0.7 to 8.2	–4.5 to 4.2	334	2,902
1993					
10 Jan	grass	1.2 to 4.0	–15.0 to –6.8	328	2,785
13 Jan	snow	0.5 to 8.9	–5.6 to –1.2	131	604
2 Mar	snow	0.7 to 6.9	–17.8 to 4.9	553	5,498
16 Mar	snow	0.6 to 12.0	–18.3 to 7.5	693	8,091
23 Mar	snow	0.3 to 4.0	–11.3 to 7.9	752	9,187

* gr–th–so = grass–thatch–soil.

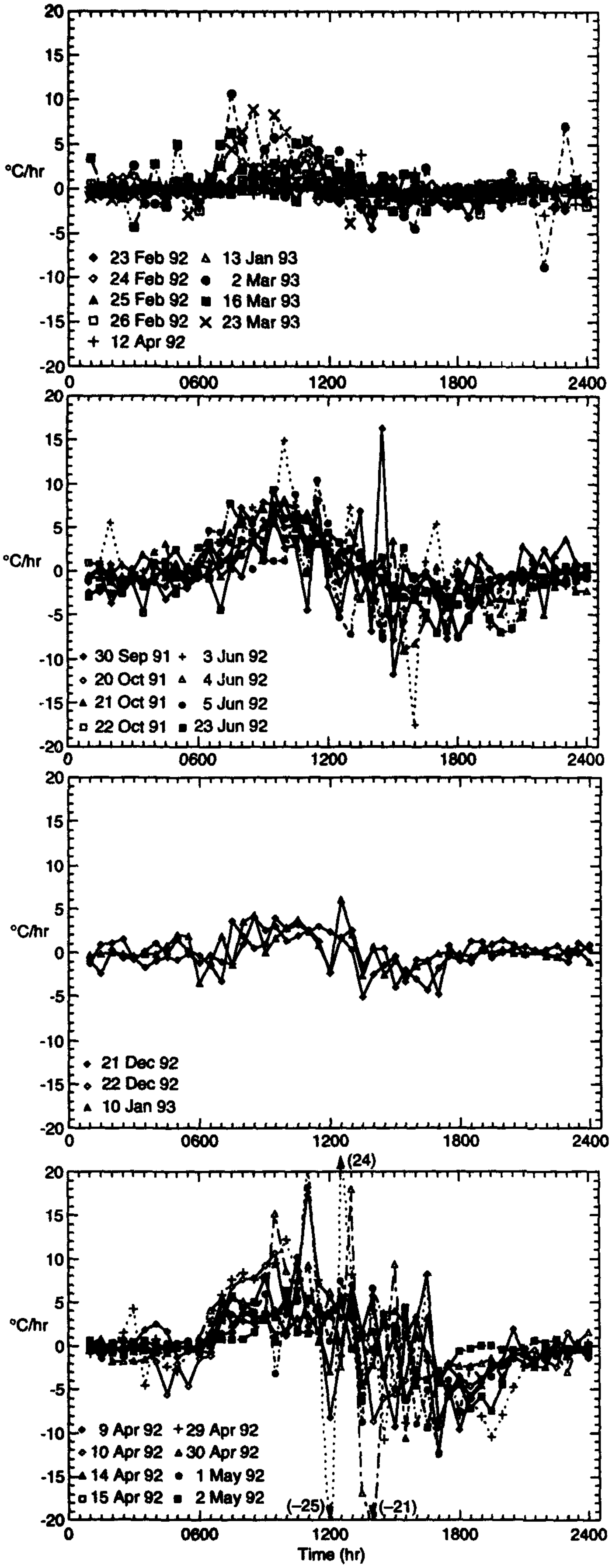
the next was then calculated as degrees Celsius per hour. The rates are plotted individually by time periods in Figure 3 for groupings by type of ground cover. The days were selected on the basis of the following criteria: they had to be 1) non-winter days having no rainfall, 2) days without interfering activity at the site, and 3) days with the most complete site characterization data. The exception to the first criterion is 2 May 1992—4.2 mm of rain fell between 0100 and 0500 hours and 15.1 mm fell between 1700 and 2230 hours, with intermittent light rainfall during the day.

Snow-covered ground

The rates of change of the surface temperature of a snow cover are given in Figure 3a. On some days (25, 26 February 1992) the rates of surface temperature change are predominantly less than 2°C/hr (absolute value) and vary little through the course of the day. These were days of moderate warming when the range of air and surface temperatures was less than 5°C. Other days (24 February 1992; 2, 16, 23 March 1993) show relatively high rates of change during the morning hours. On these days there was significant warming of the site during the morning, with air temperatures rising by 9, 23, 24 and 19°C, respectively, during the day. The snow surfaces warmed sufficiently for melting to take place on all the days, thus preventing large temperature changes during the early afternoon. The March days show the consequences of higher insolation and extended daylight hours. There is a time of year variation to the stability of a snow cover as a thermal background, with a late-winter snow cover potentially being more dynamic than a mid-winter snow cover because of the greater likelihood for significant warming during the course of a day.

Grass-covered ground

The rates of surface heating of a fully established grass cover are presented in two time groupings corresponding to growing and dormant grass. The first category is represented by days in June,



a. Snow cover.

b. Non-winter grass cover.

c. Winter grass cover.

d. Grass–thatch–soil cover.

Figure 3. Time series record of rate of change of apparent surface temperature.

September and October (Fig. 3b); the second is represented by December and January days on which there was no snow cover (Fig. 3c). For both periods there is a clearly evident diurnal cycle to the rates of temperature changes of the grass surface during the course of a day. The grass heats up throughout the morning, with the rate increasing until midday, which typically corresponds to maximum insolation; winds and evapotranspiration in the late morning and afternoon would moderate further heating of the grass surface. Exceptions to this are 5 June 1992, which was overcast during most of the morning, and 23 June 1992, which had early morning winds (gusts greater than 4 m/s from 0800 through 1800 hours). The grass cools during the afternoon in the windy period following peak insolation. This pattern persists in the winter when the grass is not covered by snow, but the magnitude of the rates of change of the grass surface temperature is approximately half that for a non-winter grass cover. This is directly attributable to the seasonal differences in weather conditions. The maximum grass surface temperature was 30–45°C for the June days, 12–25°C for the September and October days, but only –1 to 7°C for the December and January days.

Transitional ground covers after winter

The April and May days selected for this category of ground cover span a much shorter time because the vegetated surface changes rapidly from winter dormancy to summer lushness. The apparent surface temperatures used to calculate the rates strictly apply only to a distribution of thatch and exposed soil through which new-growth grass is appearing. The proportion of grass increases over the month represented. The PIR area was both more heavily trafficked and irregularly covered with flood-deposited silt, so it included more exposed soil that was eventually grassed over.

There is a larger range of rates during daylight hours for this ground cover type (Fig. 3d). One reason for this is that the period after winter at SOROIDS includes many overcast mornings. This delays or reduces the morning rate of solar warming of the surface and often results in continued warming (positive rates) into the afternoon. A second reason is that, frequently, the ground surface radiationally cools to below 0°C at night, with dew or frost forming that must evaporate or melt before solar warming of the surface can proceed. A third reason is that the temperature increase from nighttime low to daytime high is typically larger in the transitional period, 30–45°C, versus 23–37°C for a summer grass surface, although the maximum surface temperature, 21–41°C, is less than that of summer grass. The large rate of radiative heat loss from the surface components (grass–thatch–soil) and near-surface air during the afternoon and early evening is followed by relatively stable surface temperatures through midnight because of increased turbulent transfer of upper warm air toward the ground caused by the nocturnal jet (Heinemann and Martsolf 1988). Unless radiative cooling is moderated by a cloud cover or by the introduction of warm air by a frontal passage or other source, the lowest surface temperature will occur shortly before sunrise (Rosenberg 1974).

EFFECTS OF SEASONAL VARIATION OF SURFACE TEMPERATURES AND RATES OF TEMPERATURE CHANGE ON PIRS

The two surface thermal parameters that affect the proximity-to-alarm status of a PIR—the magnitude of a change in temperature and its rate of change—both significantly depend on the season at SOROIDS. The thermal radiance emitted by the surface in the wavelength band to which the PIR's thermal detectors are sensitive (8–14 µm) increases proportionally to the fifth power of the surface's temperature

$$N\,[8\text{–}14\ \mu\text{m radiance}] = 1.876 \times 10^{-11}\, T^{5.032}.$$

This equation was obtained from Plank's equation for the specific spectral band of 8–14 µm; it is valid over the temperature range of –50 to 50°C and for a surface with emissivity of 1 (Lacombe and Peck 1992). For the range of surface temperatures encountered at SOROIDS, the corresponding changes in radiance ascribable to a 1°C rise in temperature are given in Table 3. Clearly, the warmer the

Table 3. Change in thermal radiance attributable to a 1°C change in temperature.

Temp (°C)	*Radiance (W/m^2 sr)*	*Temp (°C)*	*Radiance (W/m^2 sr)*	*Δ radiance (W/m^2 sr)*
–30	19.01	–29	19.41	0.40
–20	23.29	–19	23.75	0.46
–10	28.30	–9	28.84	0.54
0	34.14	1	34.78	0.64
10	40.91	11	41.64	0.73
20	48.72	21	49.56	0.84
30	57.68	31	58.64	0.96
40	67.91	41	69.01	1.10

background scene is, the more significant to the PIR is a 1°C rise in temperature.

The second parameter is the rate of change of surface temperature. Of the various categories of ground covers at SOROIDS during the year, the snow-covered surface was the least dynamic, while the transitional ground cover after winter (grass–thatch–soil) heated and cooled most rapidly. The transitional ground cover also showed the most variation in rates, which makes it difficult to anticipate how dynamic that surface will be.

The least troublesome (lowest associated proximity-to-alarm status) background scene for a PIR, therefore, should be a snow cover, while the most troublesome background scene should be either the summer grass cover or the grass–thatch–soil ground cover.

A third factor influencing the rate of change of the thermal background scene is a different type of change in surface temperature. During the summer, the SOROIDS grass is usually long enough to blow in the wind. (The grass is mowed weekly but grows vigorously.) During the daytime there is directional warming of the grass; the portion of a grass blade that is exposed to the sun is relatively warm and the sheltered portion is cooler. Other objects in the background scene also experience a similar temperature distribution that depends on their angle of exposure to the sun. The distinctive characteristic of the grass is that it blows in the wind, with a grass blade bending sufficiently to direct variously its solar warmed or its cooler portion to a PIR. The grass motion may also momentarily expose the soil, which is generally cooler than the surface during the daylight hours (e.g., Fig. 2b). Wind-induced motion of the grass causes rapid changes in the thermal radiance directed at a PIR. This type of radiance change would be a problem only when the grass (or any vegetation) is long enough to blow in the wind, so its effect on the proximity-to-alarm status of the PIRs would be more severe in the summer than in the transitional period after winter.

24 February 1992

The proximity-to-alarm status of both PIRs on 24 February 1992 is shown in Figure 4. The voltage change is positive or negative, depending on whether the radiance change is high to low or low to high, so both maxima and minima are recorded. The voltage level for an alarm is 0.5 V above or below background level, i.e., the non-alarm band is between about 3.1 and 4.1 V. The PIRs are well below the alarm condition throughout the day, except for an alarm for both in the half-hour period ending at 1300 hours and a second alarm for PIR-West at 2235 hours. The joint alarm was caused by a person walking across the background scene in the fields of view of both PIRs at midrange; the nighttime PIR-West alarm was caused by an animal that crossed the background scene too close to the PIR-East to be within the fields of view of its thermal detectors, causing no PIR-East alarm.

The voltage range (maximum voltage–minimum voltage for the same half-hour period) of both PIRs decreases overall from 0030 hours through 1030 hours. This corresponds to warming of the snow surface from –10 to –2°C; for the remainder of 24 February, the apparent temperature of the snow surface (calculated from the upwelling [3–50 µm] radiation) was between –2 and 0°C. The proximity-to-alarm status of the PIRs is lowest while the temperature of the snow surface is stable. The small variation in surface temperature after 1030 hours is

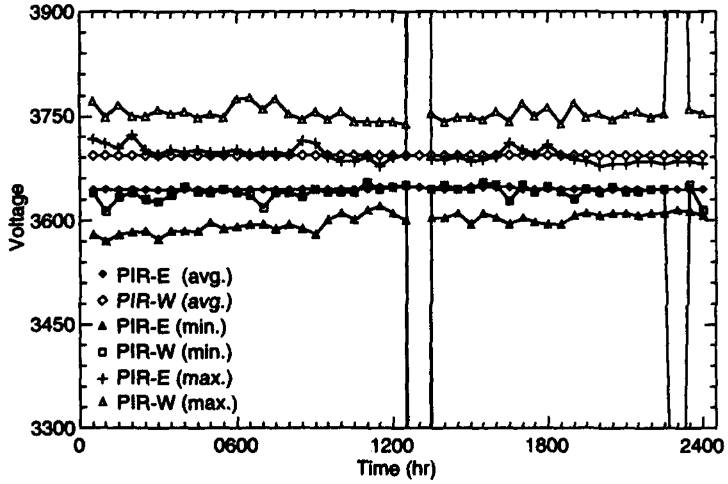


Figure 4. Time series record of test point voltages for PIR-East and PIR-West on 24 February 1992.

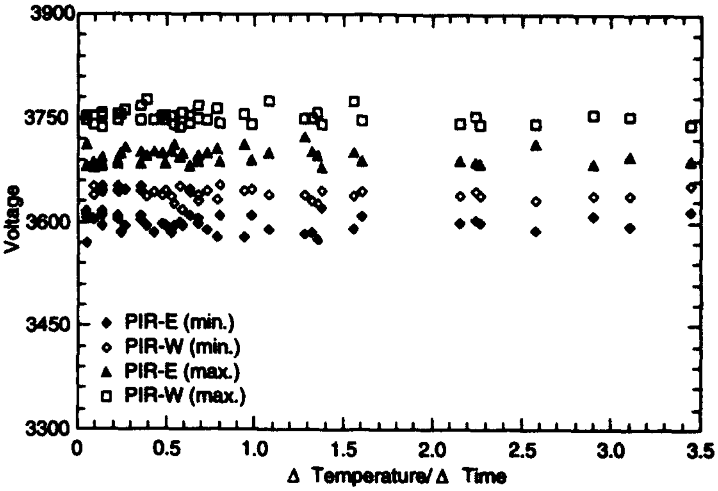


Figure 5. Maximum and minimum PIR test point voltages for a half-hour period, plotted vs. the absolute value of the rate of change (°C/hr) of apparent snow surface temperature for the same half-hour period on 24 February 1992.

evident in the low rates of temperature change that predominate on that day (Fig. 5). This was a calm day with wind gusts less than 4 m/s throughout. The proximity-to-alarm status of the PIRs on other winter days when there is a snow cover show a similar low magnitude and small range of values, even on windy days (gusts greater than 4 m/s). A mid-winter snow cover is consistently the most stable thermal background scene for the PIRs.

10 April 1992

The proximity-to-alarm status of the PIRs on this transitional day following winter is shown in Figure 6. The nighttime hours are characterized by low voltage levels and low variation, except for PIR responses to animals (half-hour periods ending at 0430, 0500 and 2400). The daylight hours are a period of persistently high voltage levels; this corresponds to the solar warming and radiational cooling of the mixed soil–grass–thatch background (Fig. 2c). Rates of change of the background surface temperature were as much as three times greater than on 24 February 1992 (Fig. 7). That factor, together with the larger radiance from the warmer surface (30 vs. 0°C, see Table 3), causes the proximity-to-alarm status of the PIRs to be high during the daylight hours.

There were three PIR-East alarms and 90 PIR-West alarms between 1000 and 1430 hours. All of these alarms were in response to changes in the thermal background scene; none were caused by a person or animal walking through the PIR area. Winds were consistently high (gusts of 6–10 m/s every half-hour from 0900 to 2330 hours) throughout the daylight period. Changes in the wind activity had no discernible effect on the proximity-to-alarm status of either PIR; it is likely, however, that the surface temperatures of the mixed ground cover were moderated because it was windy.

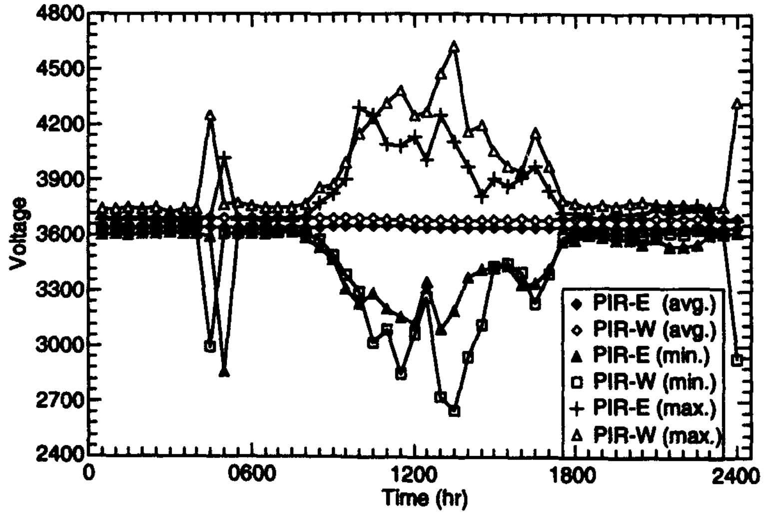


Figure 6. Time series record of test point voltages for PIR-East and PIR-West on 10 April 1992.

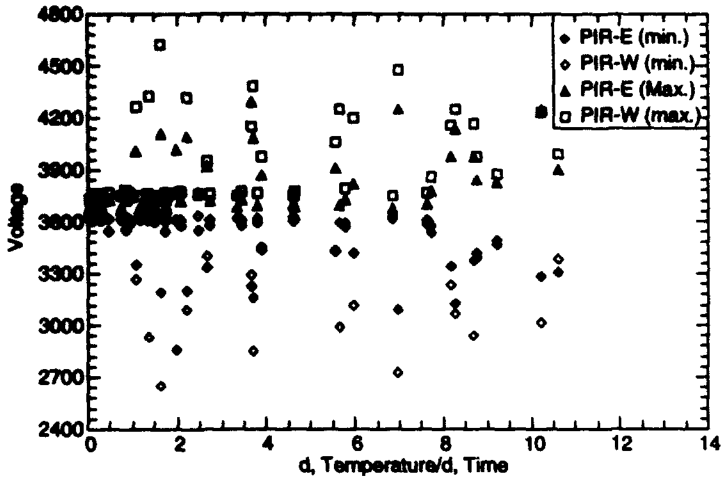


Figure 7. Maximum and minimum PIR test point voltages for a half-hour period, plotted vs. the absolute value of the rate of change (°C/hr) of apparent ground surface temperature for the same half-hour period on 10 April 1992.

23 June 1992

The proximity-to-alarm status of the PIR-East on this summer day is shown in Figure 8. As on 10 April there is substantial contrast between the proximity-to-alarm status of the PIR during daylight hours, when the background is undergoing solar warming and significant radiational cooling, and the nighttime hours when radiational cooling proceeds at a lower rate or has ceased (Fig. 2b). The only alarms (seven) occur between 0943 and 1207 hours, which is before the time when the grass background is its warmest (1430–1530 hours). The morning was a period of high wind, however, with gusts of 8–13 m/s between 0900 and 1300

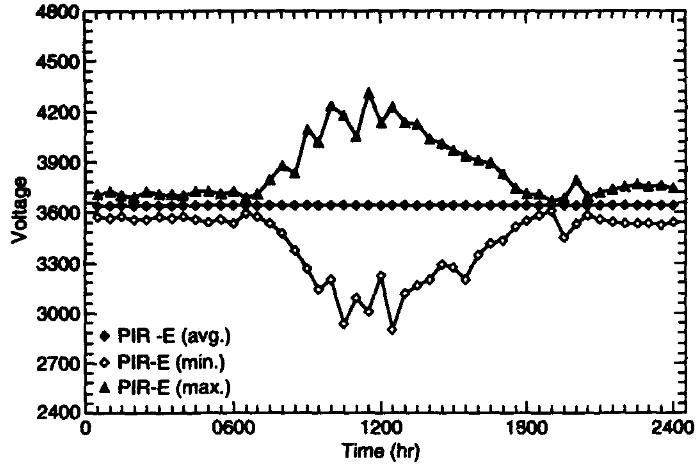


Figure 8. Time series record of test point voltages for PIR-East on 23 June 1992.

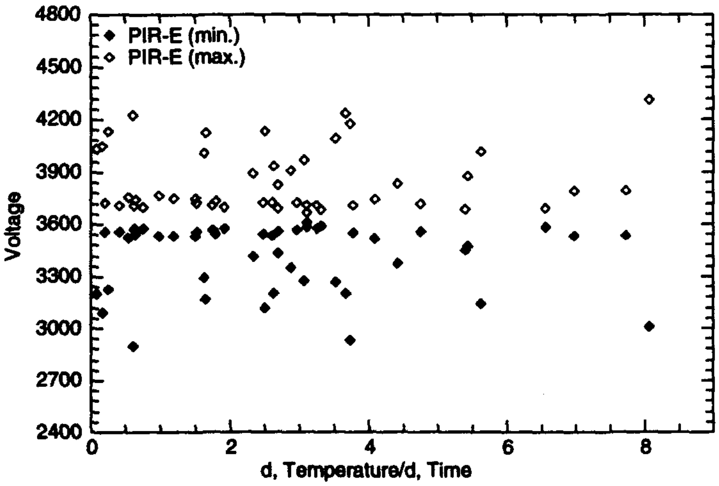


Figure 9. Maximum and minimum PIR test point voltages for a half-hour period, plotted vs. the absolute value of the rate of change (°C/hr) of apparent ground surface temperature for the same half-hour period on 23 June 1992.

hours. The PIR's proximity-to-alarm status during the morning does not follow the pattern of insolation-related changes in the surface temperature of the grass cover. Instead, its erratic variation directly corresponds to the pattern of wind gusts, and is attributable to changes in radiance caused by wind-induced motion of the grass. The overall increase in proximity-to-alarm status during the morning is caused by the warming of the grass cover, but the superimposed variations that led to alarms were caused by the motion of the grass blades, which vary in temperature from top to base, as they ripple in the wind. In the afternoon, the proximity-to-alarm status declined gradually as the grass cover cooled; this was a period of relatively low wind activity (gusts less than 6 m/s) and no alarms.

The maximum (absolute value) rate of temperature change on this day was less than that on 10 April, and the range of PIR voltages also was less (Fig. 9). If the morning had been calm, it is likely that there would have been no PIR alarms on this day; conversely, if the grass cover had been mowed so close that the blades were not long enough to bend over in the wind, then also there probably would not have been alarms on this day.

30 April 1992

A final example of the daily variation in PIR proximity-to-alarm status is that of 30 April 1992 (Fig. 10). Previous examples have been selected as being representative of the variation in thermal radiance from different background scenes (snow cover, grass cover, grass–thatch–soil). Whereas the PIR response to the snow-cover background showed little change over 24 hours, there were distinctly different daytime and nighttime levels of proximity-to-alarm status when the background was grass or grass–thatch–soil. This day is included to emphasize that the apparent daytime–nighttime differences in proximity-to-alarm status are actually differences ascribable to the amount of insolation, which on sunny days follows a daytime–nighttime pattern.

During the morning of 30 April, the level of insolation was increasing from 0600 hours on, with

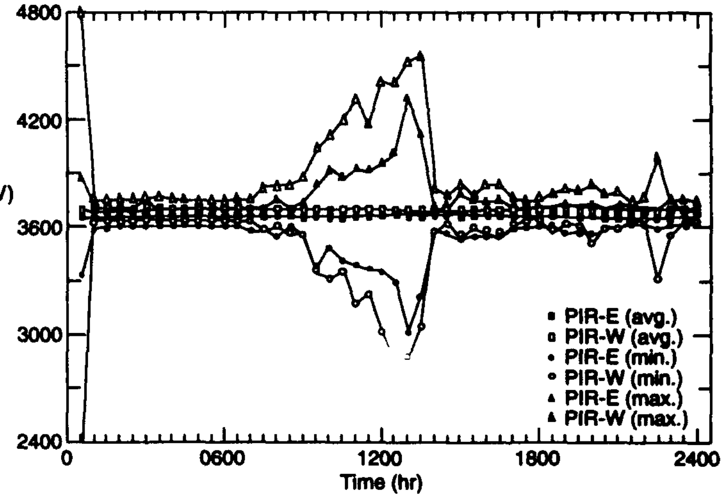


Figure 10. Time series record of test point voltages for PIR-East and PIR-West on 30 April 1992.

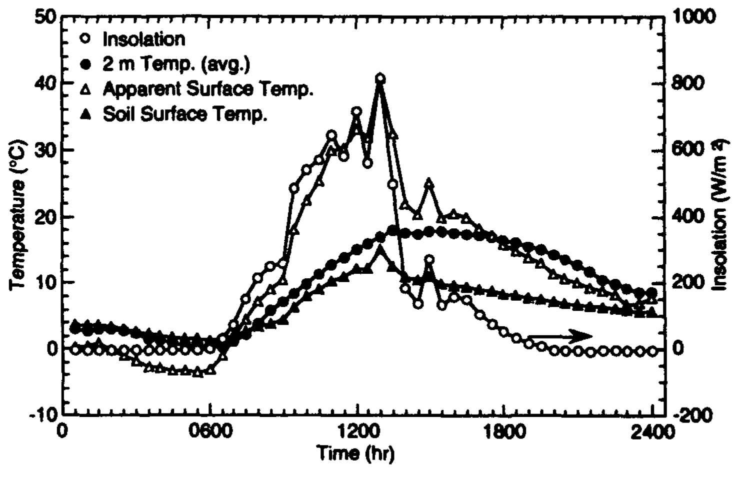


Figure 11. Time series record of air (30-minute average), ground (grass–thatch–soil) surface (calculated) and soil surface (instantaneous) temperatures and incident solar radiation (30-minute average) on 30 April 1992.

a consequent warming of the background (Fig. 11). After 1300 hours the site became overcast and insolation dropped precipitously to levels more typical of 1800 hours than 1400 hours. The corresponding change in PIR proximity-to-alarm status is equally abrupt and persists into the evening. There were seven PIR-East alarms in the half-hour period ending at 1300 hours and 58 PIR-West alarms between 1100 and 1330 hours; neither PIR gave an alarm once the sky became overcast and solar warming of the background ceased.

PRECIPITATION AND PIR PROXIMITY-TO-ALARM STATUS

Precipitation generally has no effect on or improves the PIR proximity-to-alarm status. Snowfall onto a snow cover caused no significant change in the proximity-to-alarm status of the SOROIDS PIRs. This is understandable because the new snow surface increased the temperature of the background to at most 0°C. Snowfall onto bare ground is very advantageous, particularly during the transitional periods before and after winter, because it causes an abrupt decrease in the range of surface temperatures during the daytime. In effect, it transforms troublesome thermal backgrounds such as that of 10 April 1992 into thermally stable backgrounds such as that of 24 February 1992.

Rainfall homogenizes the background because the surface becomes uniform with the emissivity of water (Shushan et al. 1991), in place of a varied background such as soil–thatch–grass, each with its characteristic emissivity.

Rainfall onto soil or vegetation suppresses surface heating by insolation. Once rainfall ceases, solar warming of the background cannot proceed until the surface has dried; strong surface heating is delayed while the rainwater evaporates. A high moisture content in the soil means that vegetation will not experience moisture stress as quickly, and so solar energy will be consumed in evapotranspiration rather than in sensible heat generation that warms the plant surfaces.

MAINTAINING ACCEPTABLE PIR PERFORMANCE DESPITE DAILY AND SEASONAL ENVIRONMENTAL CHANGES

When a passive infrared system is used for intrusion detection, acceptable performance is defined in terms of the probability of detection and the nuisance (non-intruder) alarm rate. Environmental factors that cause a PIR to have a high proximity-to-alarm status increase the likelihood that it will experience nuisance alarms. Avoiding such alarms by reducing the sensitivity of the system can lead to unacceptably low probabilities of detection. Equivalently, controlled intrusions during periods of variable proximity to alarm may result in misleading probabilities of detection owing to the environment-related bias.

Of the backgrounds considered, a continuous snow cover is best because of its low thermal radiance and spatial homogeneity (relative to the fields of view of a PIR's thermal detectors). With a snow cover, the PIR response to the ambient thermal scene is low in magnitude and varies little during a diurnal cycle. Accordingly, the PIR may be set at a high sensitivity while maintaining a reasonable proximity-to-alarm status throughout a 24-hour period.

Vegetated surfaces are more difficult for maintaining acceptable PIR performance because potentially they experience a greater range in surface temperatures over a diurnal cycle, greater rates of change of surface temperature during solar warming and radiational cooling, higher temperatures and therefore higher emitted radiances, and wind-induced motion. One way to prevent the nuisance alarms is to monitor the PIR test point voltage output and adjust the PIR sensitivity whenever the proximity-to-alarm margin becomes too small. (The advisable margin between the test point voltage and the alarm condition voltage will be site specific and vary seasonally.) A less certain way is to monitor the site conditions that cause the PIR's proximity-to-alarm status to vary, and deduce what change in PIR response probably is occurring because of observed changes in site conditions—i.e., whether the proximity-to-alarm margin is likely to be increasing, decreasing or unchanged—and to change the PIR's alarm sensitivity accordingly. The examples given in this report illustrate the environment–PIR interaction for grass covers and mixed backgrounds of soil–thatch–grass. Lacombe (1993) considers other backgrounds, such as asphalt, concrete and sand.

Alternatively, in situations where the PIR sensitivity is not to be changed by security personnel, the proximity-to-alarm monitoring may be used instead to assess the probable causes of alarms. For example, an isolated alarm during a period of low proximity-to-alarm most probably will be an intruder, while an alarm during a period of high proximity-to-alarm will more likely be environmentally related.

CONCLUSIONS

The diurnal variations in surface temperature and the rate of change of surface temperature together are excellent indicators of changes in the proximity-to-alarm status of a passive infrared (PIR) intruder detection system that responds to the magnitude and differential rate of change of detected thermal radiance. A typical transitional ground cover after the winter is a thermally dynamic background because of the different solar albedos and heat capacities of the exposed surfaces (grass–thatch–soil) and because of the extreme temperature variations between daytime and nighttime. A spatially homogeneous background, such as a snow cover or a grass cover, is more thermally stable for a PIR than is a mixed background; the snow cover is the least troublesome background because its range of temperatures is more limited and its thermal radiance is significantly less. Both summer and winter grass covers show a diurnal pattern of solar warming during the morning and radiational cooling during the afternoon; for a given rate of change of surface temperature, however, this has less effect on a PIR's proximity-to-alarm status in the winter because the associated radiance changes are less then.

By grouping time series records of surface temperatures and rates of surface temperature change together for similar backgrounds, it is possible to identify patterns of seasonal differences in the proximity-to-alarm status of PIRs. Although the actual changes in proximity-to-alarm status are specific to sites having the ground covers and weather conditions like those at SOROIDS, the pattern of seasonal change is applicable to any site.

LITERATURE CITED

Brunet, Y., M. Nunez and J.-P. Lagouarde (1991) A simple method for estimating regional evapotranspiration from infrared surface temperature data. *ISPRS Journal of Photogrammetry and Remote Sensing*, **46**: 311–327.

Budyko, M.I. (1974) *Climate and Life*. New York: Academic Press.

Desrochers, D.T. and H.B. Granberg (1986) An investigation of woodland snow thermal regime in the Schefferville Area, Northern Quebec. In *Proceedings of Eastern Snow Conference*, p. 204–211.

Heinemann, P.H. and J.D. Martsolf (1988) Prediction of cooling of a nocturnal environment using two atmospheric models. *Journal of Applied Meteorology*, **27**: 473–481.

Lacombe, J. (1992) Performance predictions for a passive infrared intrusion detection system. In *Proceedings, 33rd Annual Meeting of the Institute of Nuclear Materials Management, 20–22 July 1992, Orlando*, p. 133–140.

Lacombe, J. (1993) Impact of different backgrounds on thermal infrared IDS performance. In *Proceedings, 34th Institute of Nuclear Materials Management Annual Meeting, 18–21 July 1993, Scottsdale, Arizona.*

Lacombe, J. and L. Peck (1992) Analysis of a passive infrared perimeter security system. USA Cold Regions Research and Engineering Laboratory, CRREL Report 92-11.

Lunardini, V.J. (1981) *Heat Transfer in Cold Climates*. New York: Van Nostrand.

Motoyama, H. (1990) Simulation of seasonal snowcover based on air temperature and precipitation. *Journal of Applied Meteorology*, **29**: 1104–1110.

Munn, R.E. (1966) *Descriptive Micrometeorology*. New York: Academic Press.

Peck, L. (1992) Winter and transitional environmental effects on the reliability of exterior intrusion detection systems. USA Cold Regions Research and Engineering Laboratory, CRREL Report 92-10 (Confidential).

Porkhaev, G.V. (1959) *Principles of Geocryology*, part 2, chapter 4. Moscow: Academy of Science of the U.S.S.R. (translation by National Research Council of Canada, Ottawa, NRCTT-1249, 1969).

Rosenberg, N.J. (1974) *Microclimate: The Biological Environment*. New York: John Wiley.

Soer, G.J.R. (1980) Estimation of regional evapotranspiration and soil moisture conditions using remotely sensed crop surface temperatures. *Remote Sensing of Environment*, **9**: 27–45.

Shushan, A., Y. Meninberg, I. Levy and N.S. Kopeika (1991) Prediction of thermal image quality as a function of weather forecasts. *Optical Engineering*, **30**: 1709–1715.

Sturm, M. (1991) The role of thermal convection in heat and mass transport in the subarctic snow cover. USA Cold Regions Research and Engineering Laboratory, CRREL Report 91-19.

Van Wijk, W.R. (1966) *Physics of Plant Environment*, chapter 3. Amsterdam: North Holland.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 1993	

4. TITLE AND SUBTITLE

Thermal Variation in Vegetated or Snow-Covered Background Scenes and Its Effect on Passive Infrared Systems

5. FUNDING NUMBERS

MIPR F4760-93-AVJ213

PR: 4A762784AT42
WU: AT42-CH-PO1

6. AUTHORS

Lindamae Peck

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER

CRREL Report 93-22

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Air Force Electronic Security and Communications Center
Hanscom Air Force Base, Massachusetts

Office of the Chief of Engineers
Washington, D.C. 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

Available from NTIS, Springfield, Virginia 22161.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The diurnal and seasonal variations in the magnitude of and rate of change of surface temperature have been investigated for vegetated and snow-covered ground under winter, summer and transitional weather conditions at a site in Vermont. The variability in thermal radiance is evident as changes in the proximity-to-alarm status of passive infrared detection systems. A mid-winter snow cover is the most favorable background because its associated thermal radiance changes are less dynamic than are the radiance changes of uniform grass covers in summer or mixed backgrounds of grass–thatch–soil following winter. Grass–thatch–soil backgrounds typically experience a larger diurnal range in temperature (from nighttime low to daytime high) and greater spatial variability in thermal radiance than do the uniform grass covers. The summer grass is more likely to be long enough to blow in the wind, thereby causing a change in thermal radiance as variously the sun-warmed, upper portion of the grass blades or the shaded (and therefore cooler) basal portion of the grass blades, and perhaps the sheltered soil, are momentarily exposed to the passive infrared system.

14. SUBJECT TERMS

Detection capability	Passive infrared sensors
Environmental effects	Perimeter security
Intrusion detection	Sensors

15. NUMBER OF PAGES 22

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102